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REBCO Coated Conductors for Magnets

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Themes mentioned in my abstract

- Magnets are now a driving market for CC manufacture, especially with Fusion interest
- Operation of CC in ultra high fields (UHF, i.e. stronger than LTS) is stressful!
- Conductors are slit – slitting creates edge damage and screening currents may amplify local stresses – these will be preferential sites for early failure and fatigue
- CC are the vortex pinners playground – optimized nanostructures generate a very strong pinning landscape – ($F_p(H)$ > 1000 GN/m^3, 50 x Nb-Ti) – is it everywhere possible to optimize the pinning, especially in long-length manufacture?
- CC are significantly anisotropic and this has real consequences for solenoid magnet design – need ways to mitigate the anisotropy
- There are ~10 CC manufacturers world wide – why buy from one and not another?

These thoughts have been developed in a very productive collaborative environment

- In the Monday NI magnet meeting run by Seungyong Hahn and myself (Xinbo Hu, Kwangmin Kim, Kwanglok Kim, Michael Small, Griffin Bradford)
- The broader REBCO characterization group of Dima Abraimov, Ashleigh Francis, Jan Jaroszynski, Lance Cooley, Fumitake Kametani, Virginia Phifer and Anatoly Polyanskii
- In the broader MagLab thrust to put HTS into new generations of high field magnets, first 32 T, now 40 T (Project leader Hong Yu Bai and team leaders Ian Dixon and Ernesto Bosque (Huub Weijers) and PIs Greg Boebinger, Mark Bird and Lance Cooley with Tom Painter, Bob Walsh and Kyle Radcliff
- In the collaborations with ACT and SuperPower who have made exceptional conductors for magnet use
- In the HEP desire to get HTS into 20 T dipoles, where Bi-2212 is perhaps the present dominant driver (why 2212, why not REBCO?)
- In this community of high field magnet builders: MagLab, RIKEN, Tohoku, IEE-CAS, Grenoble, KBSI, LBNL, CERN, Bruker-Biospin……

Many want to put REBCO into Ultra High Field Magnet (UHF*) use – few succeed in doing it without damaging the conductor somewhere?
Are there consequences of this damage that may be hidden at first but gradually – or catastrophically - become apparent?
***UHF – anything not possible with Nb-Ti and Nb_3Sn**

UHF magnets put CC into high stress environments – screening currents amplify JBr stresses

- Is the response of the CC generic or determined by specific features of the conductor itself?
- If so what are the important defects that matter and how do they interact with the stresses?
- What models are needed and do we yet have them?
  - How can we validate the models and do we have the right codes and the right test beds to do this?

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Stress and strain analysis of a REBCO high field coil based on the distribution of shielding current

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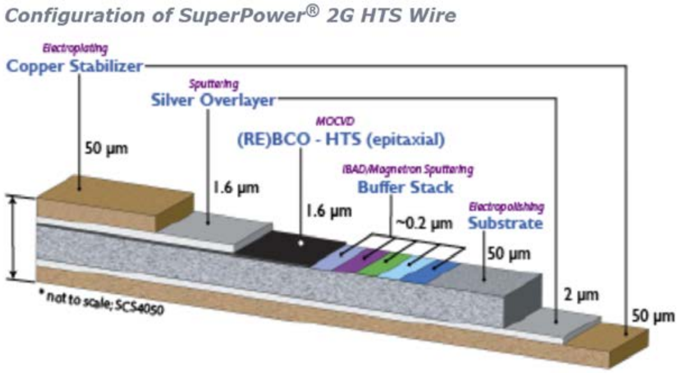
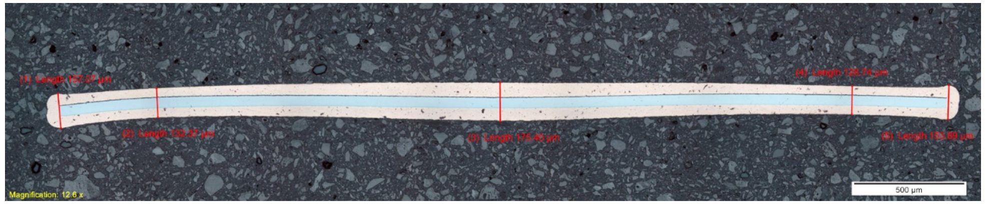
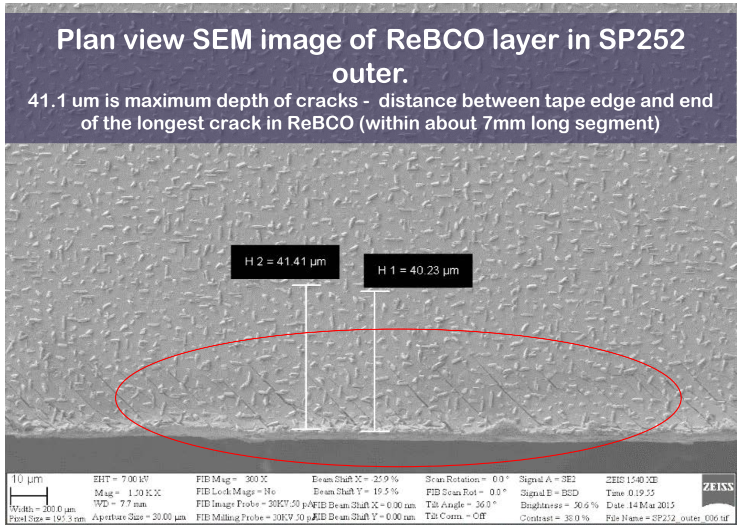
At the MagLab-ASC our R&D torture chamber is the 50 mm RT bore (37 mm He bore) 31 T magnet

REBCO is fastest present route to the highest fields – only full-width conductors avoid slitting damage







Oblique cracks are generated during slitting, setting up places for fatigue damage: fatigue testing is vital for any user magnet – but with what damage spectrum?

This 32 T conductor was neither rectangular, nor undamaged, when wound into the magnet and risks to become even more damaged after being in service, demanding much closer attention to (local) stress state(s)

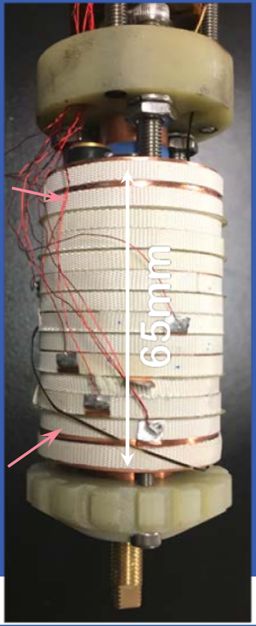
How far can REBCO be driven?

- Seungyong Hahn and I asked this question using his No Insulation tape-winding technique
- In 2017-2018 we ordered the latest 30 μm substrate conductors being made by SuperPower because it seemed that they could offer $J_{winding}$ > 1000 A/mm^2
- A field greater than the 45 T hybrid (33 MW resistive magnet inside a large 11 T Nb_3Sn magnet) user magnet at the NHMFL seemed possible using 30μm Hastelloy + 10 μm Cu and NI pancake winding.
- We were limited to the 37 mm diameter cryostat of the 50 mm bore 31 T resistive magnet at the NHMFL
  - ID of magnet 14 mm, OD 34 mm and height 50 mm – small!
  - Previous insulated layer-wound REBCO with 50 μm substrate achieved 35.4 T (40 μm Cu) in 31 T.

The Little Big Coil NI coil went through 3 iterations..(LBC1-3)

- All consist of 12 pancakes with 7 and 17 mm inner and outer radius
- All tested in a background field of 31 T.
- LBC3 – 45.5 T

P1



P12

Outer

P1
P2
…
P11
P12

Bottom

Coil cen

Outer

After achieving 45.5 T, we noticed some joint resistance: after unwinding.....

Multiple pancakes showed rippling (permanent plastic deformation of the tape (YS ~ 1 GPa, ~ 2 x nominal JBr stress

45.5-tesla direct-current magnetic field generated with a high-temperature superconducting magnet

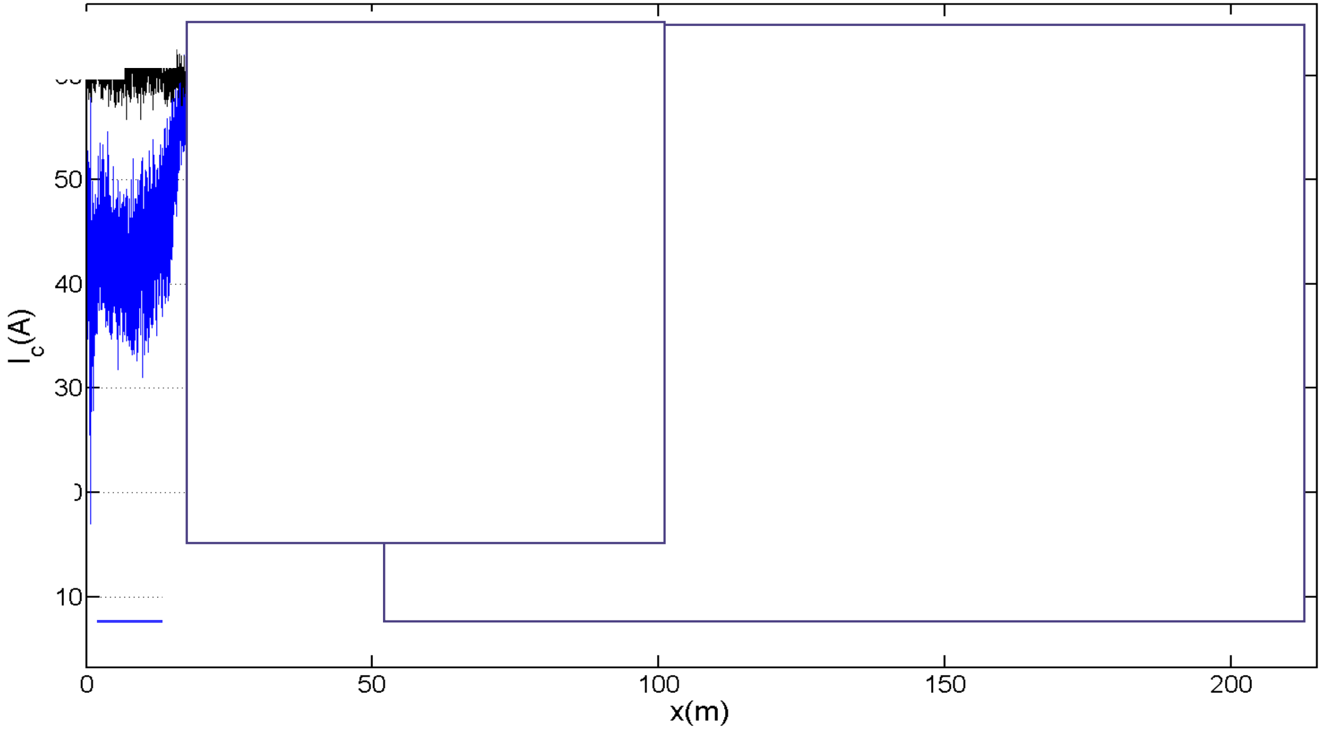
Seungyong Hahn[1,2], Kwanglok Kim[1], Kwangmin Kim[1], Xinbo Hu[1], Thomas Painter[1], Iain Dixon[1], Seokho Kim[1,3], Kabindra R. Bhattarai[1,4], So Noguchi[1,5], Jan Jaroszynski[1] & David C. Larbalestier[1,4]*

Nature 570, 497 June 2019 https://doi.org/10.1038/s41586-019-1293-1

LBC provides an extreme test bed far beyond user magnet specification

- One edge of the tape is stretched longer than the other.
- Plastic deformation of the conductor occurs in the radial direction.

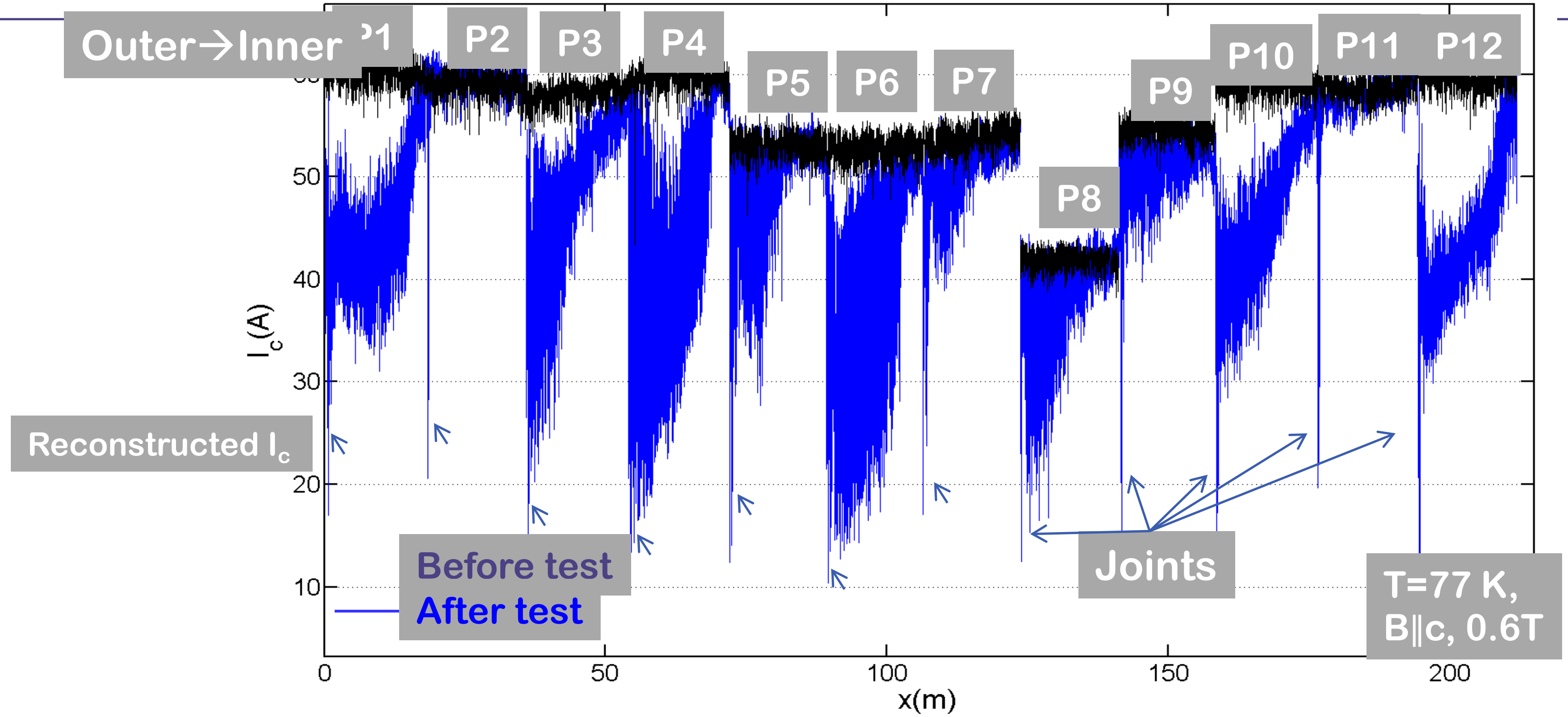
Using our transport and Hall array in-line measurement system (YateStar) we found clear evidence of conductor damage AFTER test



Black traces before test, blue traces are after test

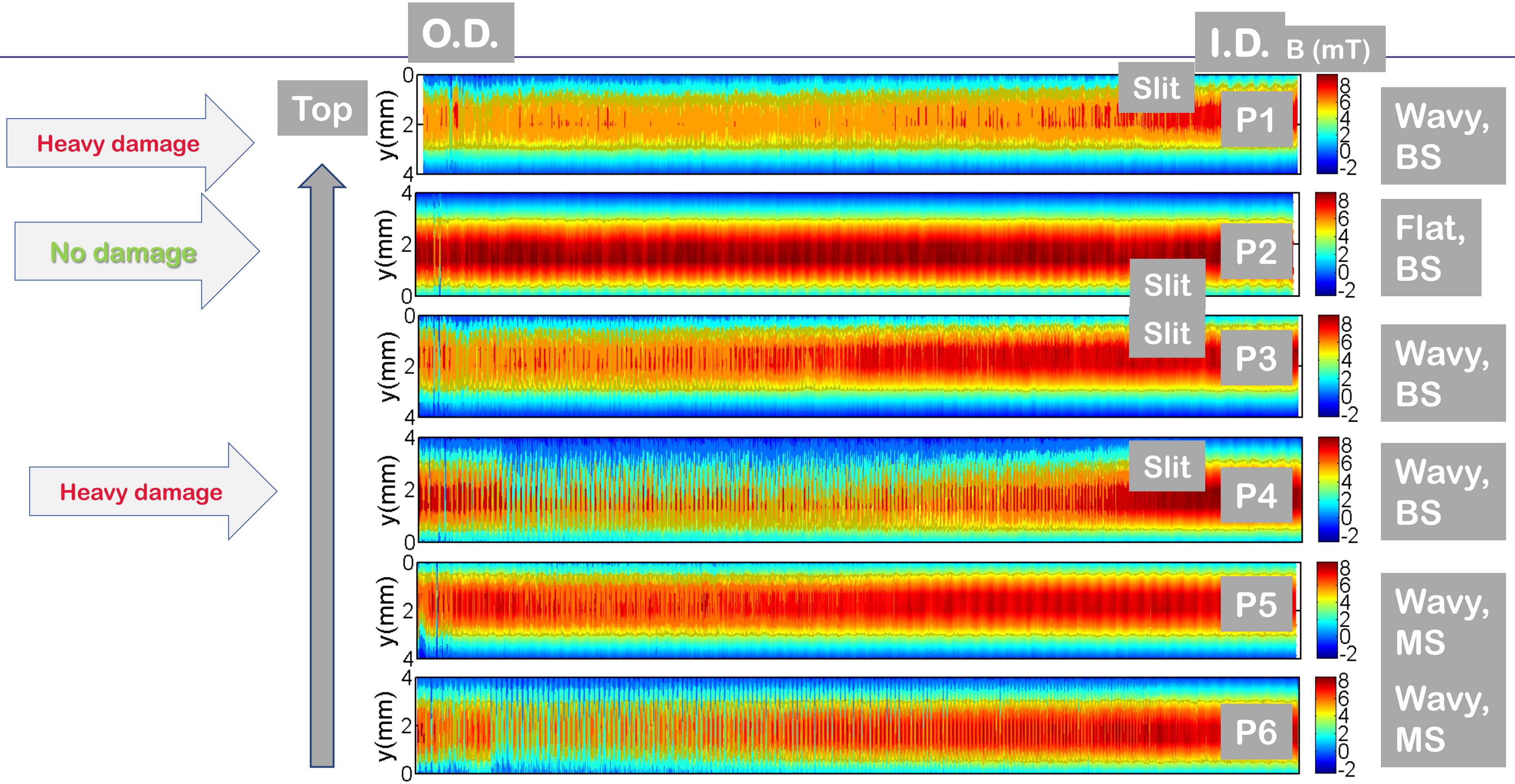
Paul Hu, Kwanglok Kim and Kwangmin Kim

Using our transport and Hall array in-line measurement system (YateStar) we found clear evidence of conductor damage AFTER test for all pancakes EXCEPT PC 2 and 11



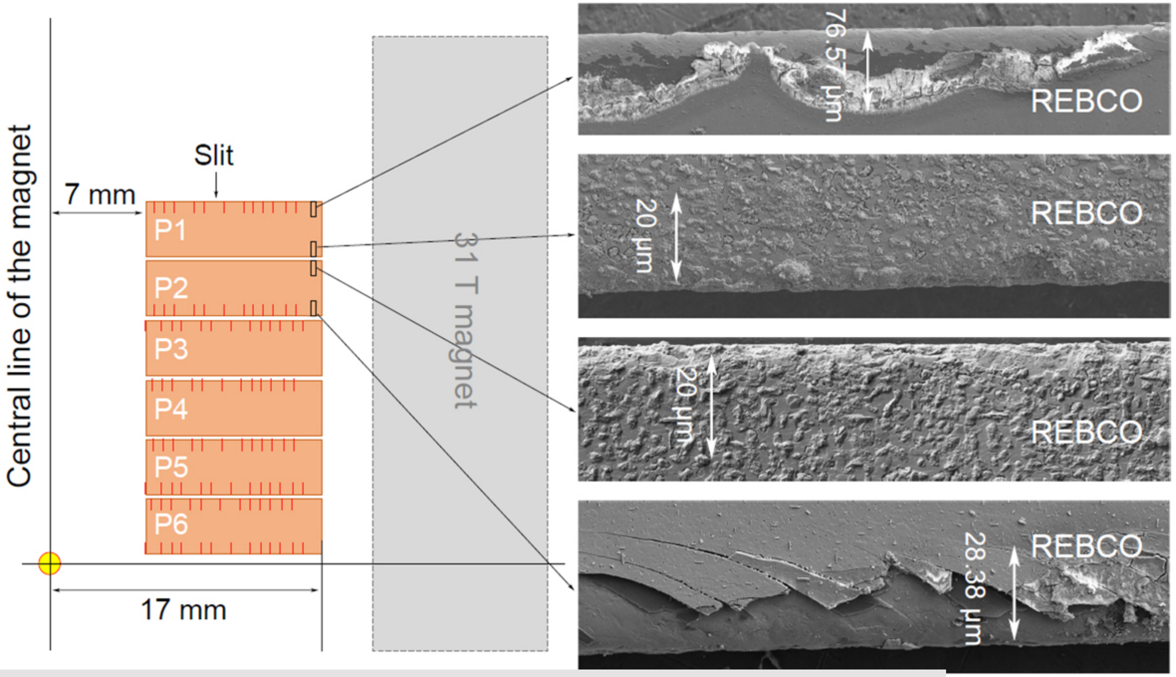
- The big dropouts on outer turns came from outer solder joints.
- Maximum degradations are close to the outmost turns but not on them.
- Indications of hoop stress occur on outer turns which we believe occurred during quench rather than from energization to field (Note that PC 2 and 11 do NOT have this damage).

Hall array shows up the damage very clearly too – and its preference for one edge



Degraded edge matches the wavy edge.

An important observation is that the slit edge is more easily damaged when placed towards the outside of the magnet



Delamination on the slit edge

No damage on not-slit edge

No damage on not-slit edge

Delamination on the slit edge associated with slitting cracks

Paul Hu, Kwanglok Kim and Kwangmin Kim

Although LBC3 operated far beyond the design strains of any user magnet, it shows that the likely long-term behavior of the tape under fatigue and elastic-plastic deformation of the Ag-REBCO-buffer interface needs to be much better understood

Little Big Coil (LBC) Summary: An extreme test bed that shows up many issues

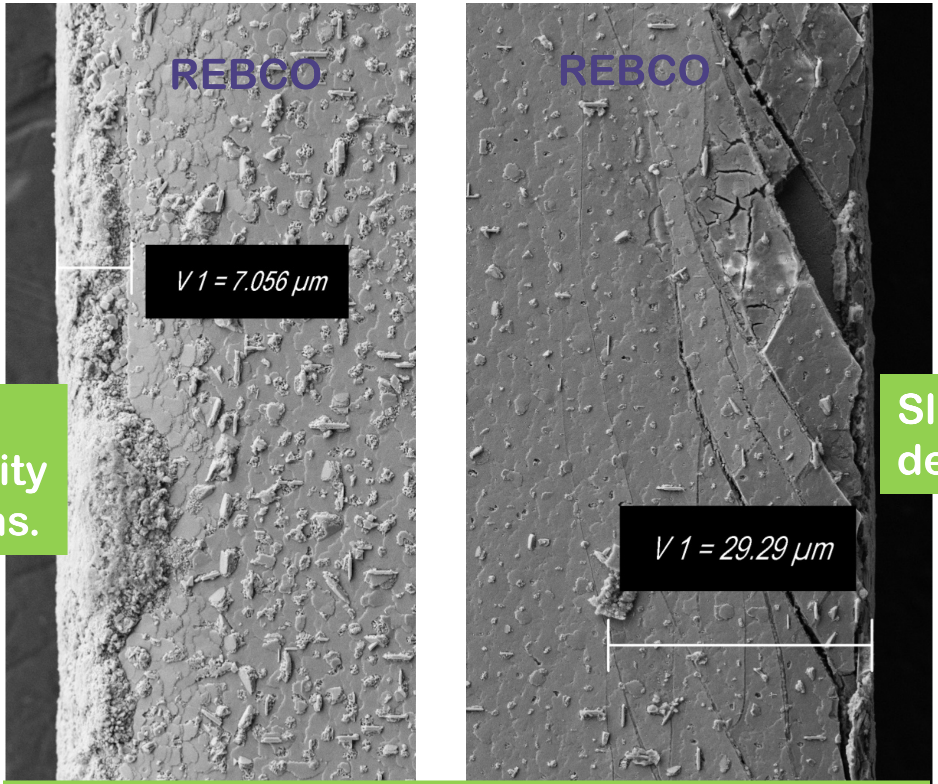
- Macroscopic calculations do not predict what happened to LBC
  - In principle turns are self-supporting and expand away from each other: $\sigma = JBr$ (nominally 691 MPa, total strain 0.38%)
    - But screening currents amplify and introduce position dependence to the local stress
    - Tape was plastically rippled on one edge with ~ 1 ripple per turn after test for most pancakes, but not when the slit (damaged) edge of a single-slit tape was placed on the inside edge
    - The coil quenched at 45.5 T and because we noticed extra joint resistance after the quench we elected to post mortem the coil by unwinding it and running it through YateStar
      - Modelling of the quench (Kabindra Bhattarai et al. SuST 2019 https://doi.org/10.1088/1361-6668/ab6699) suggests that the increasingly degraded crack pattern seen in most tapes is associated with overcurrent as the quench progressed

But PC 2 and 11 with (coincidentally) their slit edges on the magnet center side were NOT rippled, NOT edge damaged and NOT overstressed by the quench

What happens at the slit edge?

- Most slitting is done mechanically with a high-tech pizza wheel – some with laser
- At present there is no specification for the residual slitting damage that we are aware of

Very recent MOCVD tape



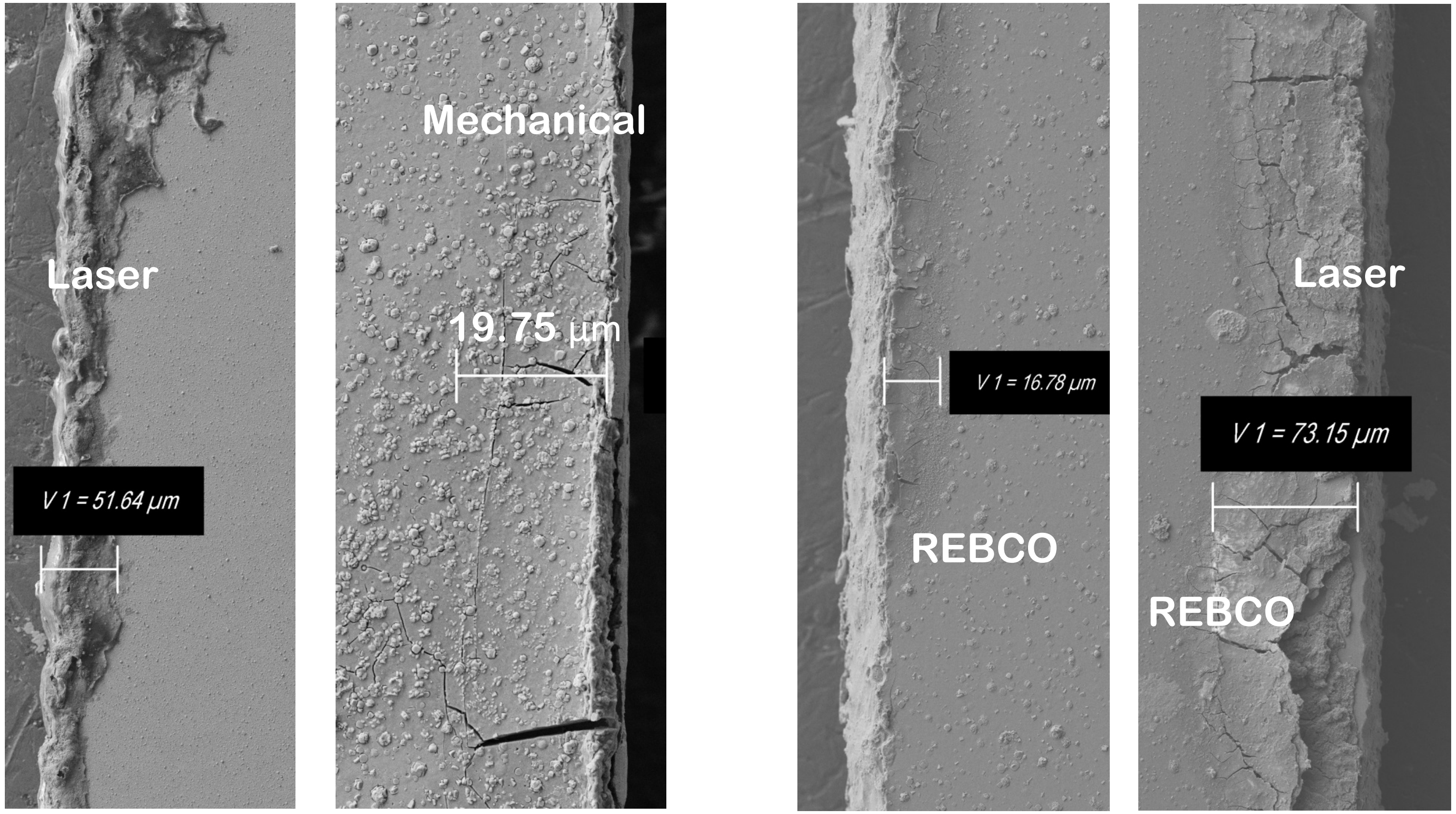
Not-slit edge has high density of a-axis grains.

Slit edge has high density of cracks

Image of REBCO layer after etching away Cu and Ag

Paul Hu

Laser slitting may be an option but is clearly not yet perfect, perhaps due to overheating



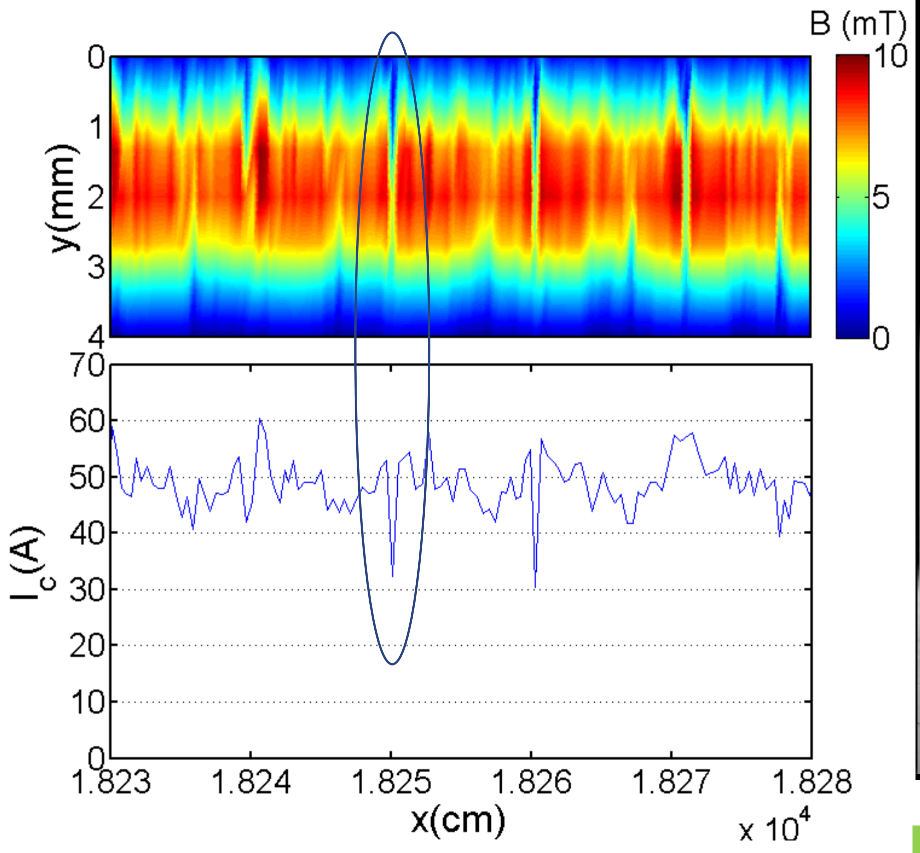
Paul Hu

Under evaluation (in service yet?) by several manufacturers

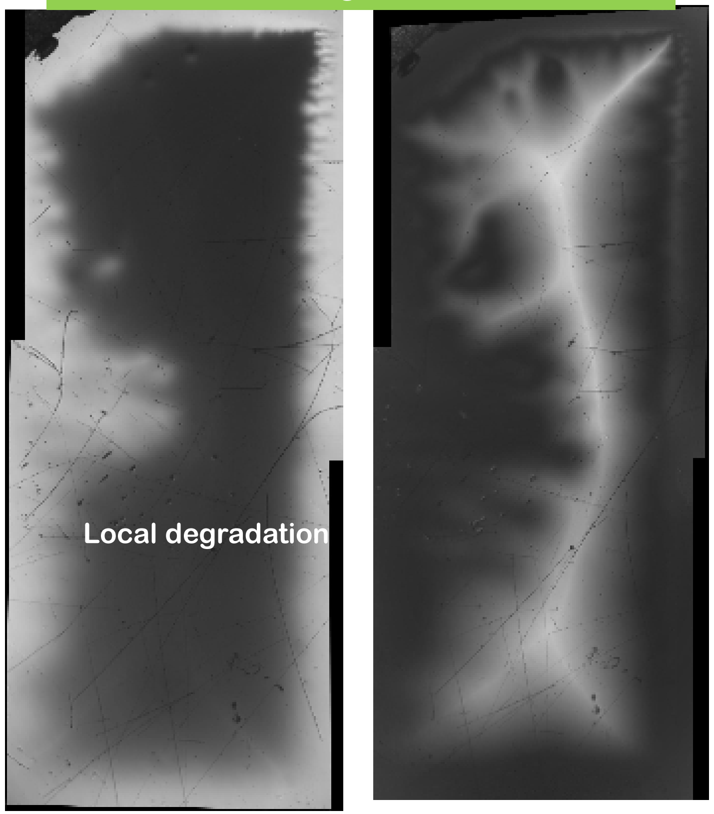
How does such pre-existing damage propagate in an LBC coil (in this case LBC2 which got to 42.5T)?

- Local damage region identified in YateStar and cut out for SEM and Magneto-optical imaging (MOI)
- We did not run YS beforehand in this case

Paul Hu, Griffin Bradford and Tolya Polyanskii



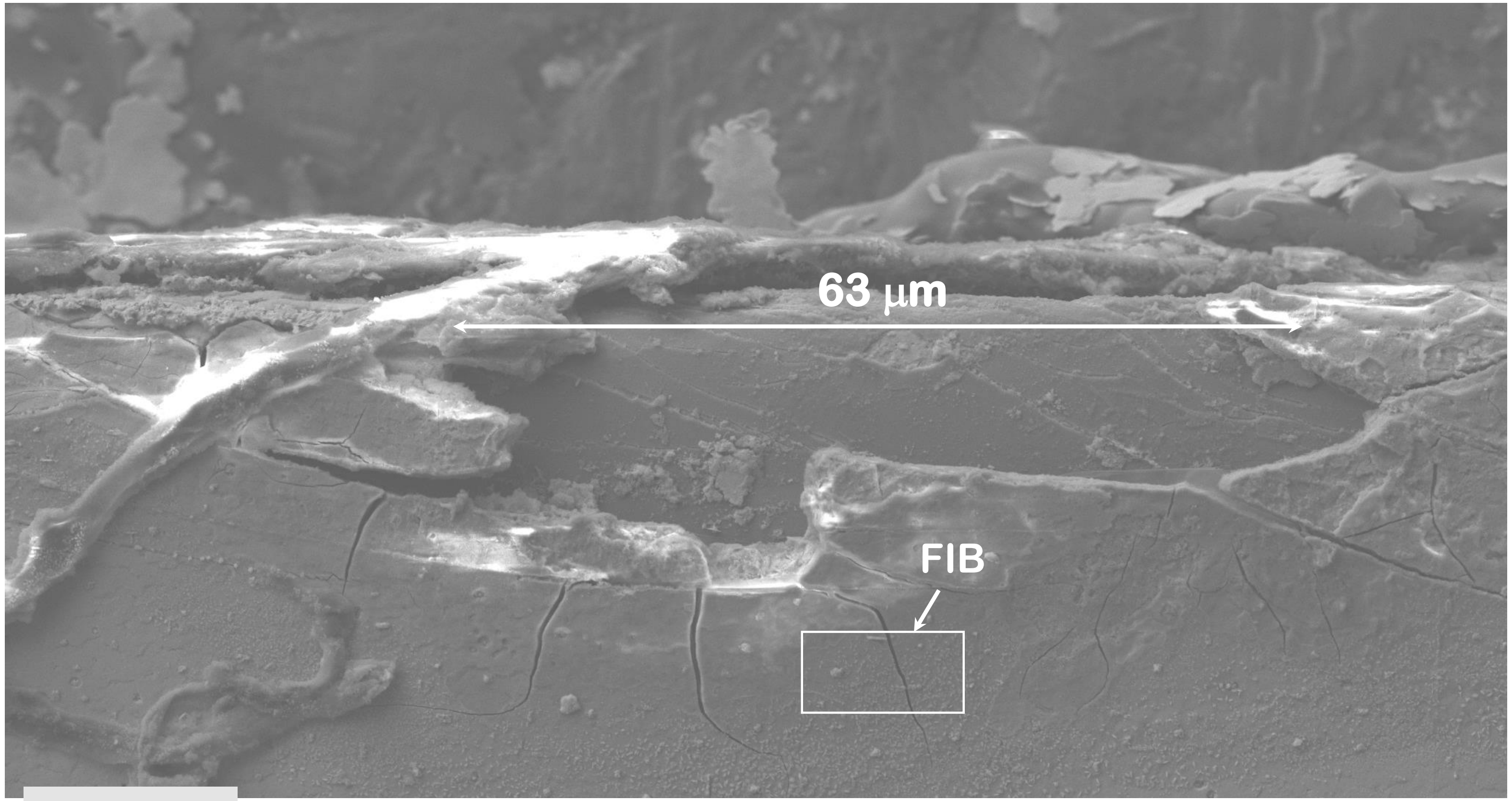
See SEM of damage zone on next slide



ZFC T=10K H=80 mT

T=60K H=0 FC in H=120 mT

Top view of the damage zone in the MO image of last slide : REBCO has delaminated from the buffer layer (LBC2 after test)



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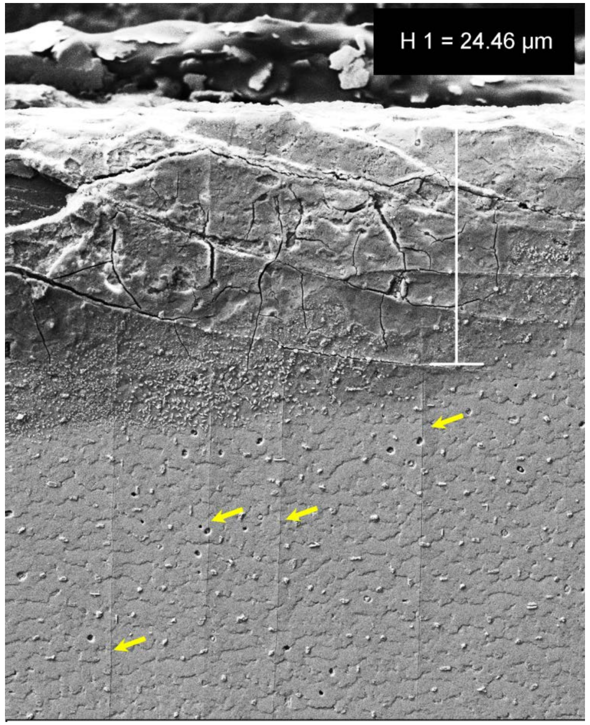
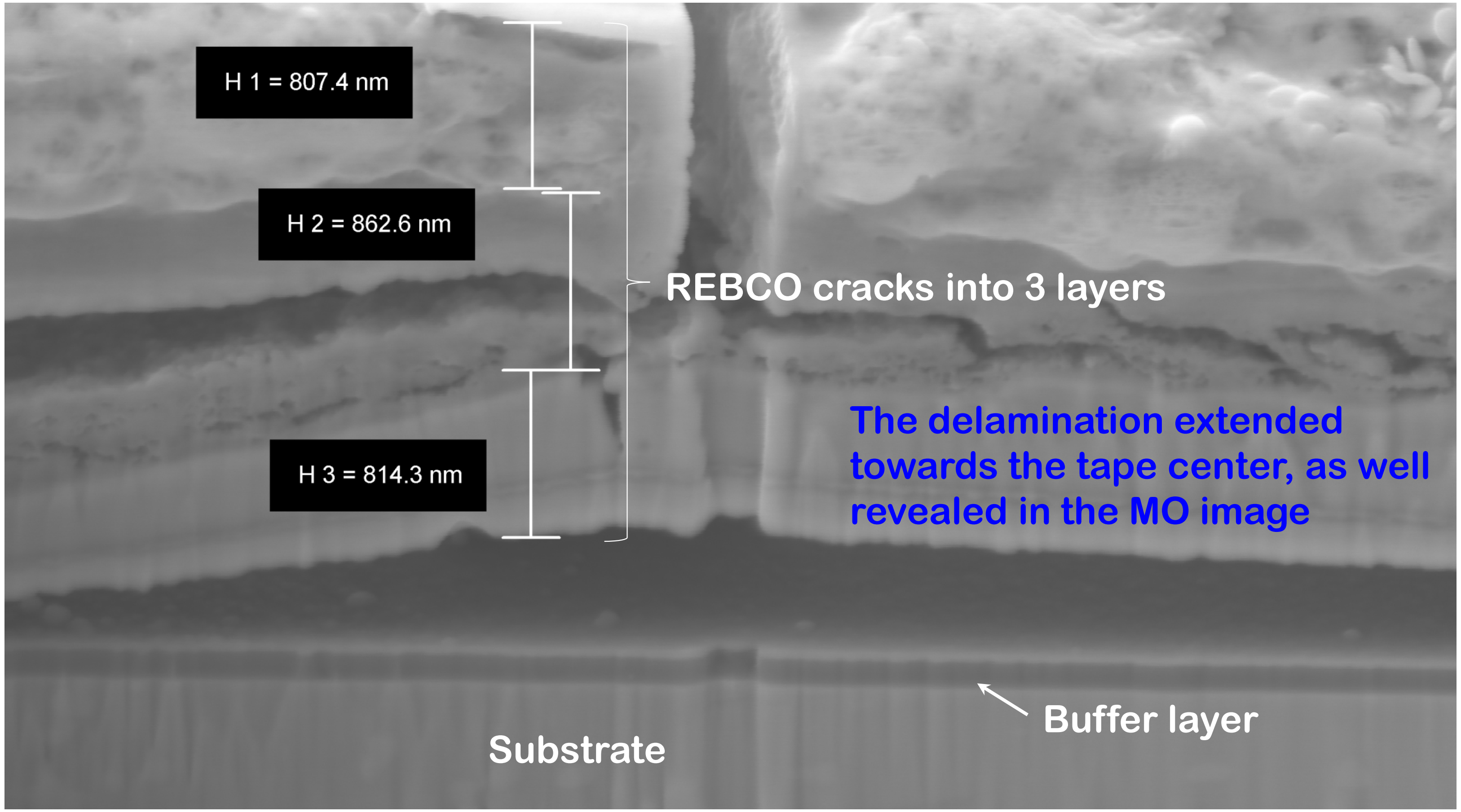


Transverse cracks, ~1 mm in length after LBC test to 42.5T

Cracks propagate within the REBCO layer itself. Buffer layer and substrate look good and REBCO delaminates at buffer-REBCO interface (LBC2 after 42.5 T test).



Paul Hu

Summary of extreme damage in LBC 40, 42.5 and 45.5 T coils

- The JBr stresses are high but not exceptional (yesterday stresses of 400-600 MPa were mentioned in recent RIKEN and Tohoku test coils)
- The coil stresses clearly interact with the pre-existing slitting defects (whose type and density we did not know of in advance)
  - Note that the damage was avoided by placing the slit edge towards the magnet center, strongly suggesting that it is the interaction of the transport current and the slit edge defects that delaminates and causes crack propagation.
- These are largely single test damage results:
  - What about fatigue over many cycles?
- These results prompted us to go and back and review some early analytical work by Alex Gurevich, recently re-considered by Dima Abraimov

Non-linear I-V curves produce highly localized electric fields (recent considerations by Dima Abraimov): important to consider at defects

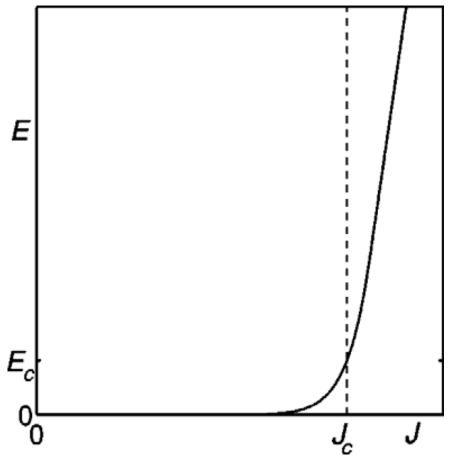


FIG. 1. E-J characteristic of a type-II superconductor. J_c marks the crossover from flux creep to flux flow.

Figure 1 shows a typical E-J characteristic, which is **highly nonlinear** in the flux creep regime $J<J_c$ and becomes linear in the flux-flow state $J \geq J_c$

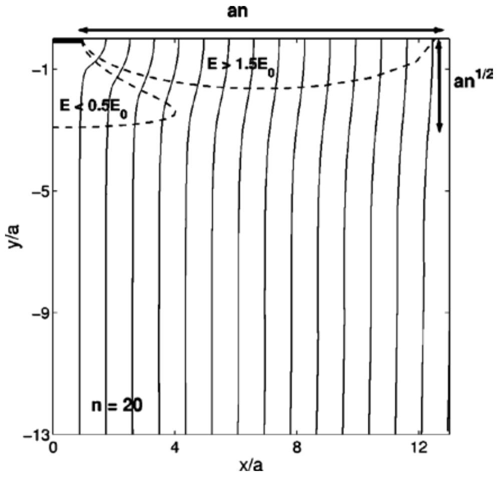


FIG. 3. Current streamlines around a planar defect in an infinite superconductor with $E=E_c(J/J_c)^n$, n=20 (Refs. 22 and 23) (only one quadrant is shown.) Dashed lines show the boundaries of the flux jet and stagnation region.

M. Friesen, A. Gurevich, PRB 63, 064521 (2001)

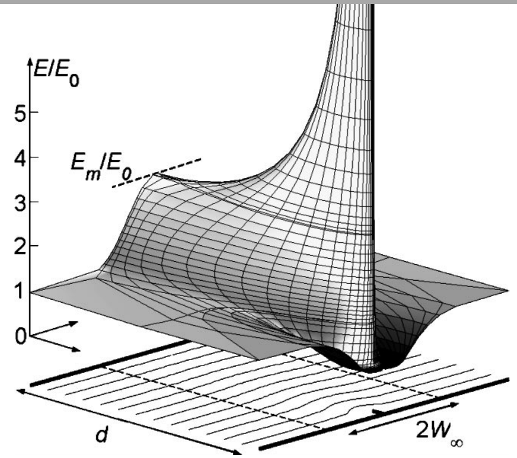


FIG. 16. Spatial distribution of the magnitude of the electric field $E(x,y)$ for 5% crack-in-film geometry, with n=30. (Surface plot is shifted upward to show the underlying current streamlines.)

In general, the relation between the global $\bar{E}(J)$ and the mesoscopic $E(J)$ characteristics can be rather complex, because of the percolative nature of current flow in HTS and the **nonlinearity** of the E-J relation.

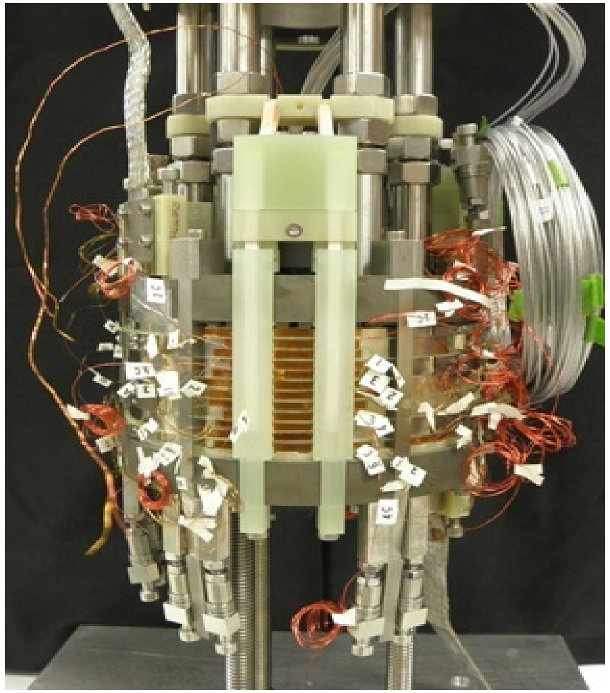
Some lessons (and questions) from 32 T

- The conductor may be highly variable even if bought to a standard specification
  - Manufacturer is generally selling into a 77 K, self field specification
  - Magnet builders want a 4 K, high-field, off-axis specification
- Pancakes allow grading which is helpful for addressing the varying radial field
- Why do 4 K properties vary and what issues might such variations cause?

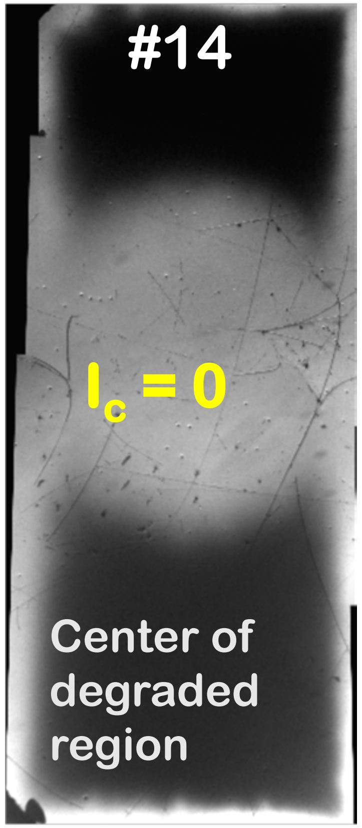
(The still unexplained) spontaneous quench of the 32 T prototype coil under rapid cycling – main question: why was damage so localized?

32 T project manager Huub Weijers

Post mortem lead by Paul (Xinbo) Hu



The coil

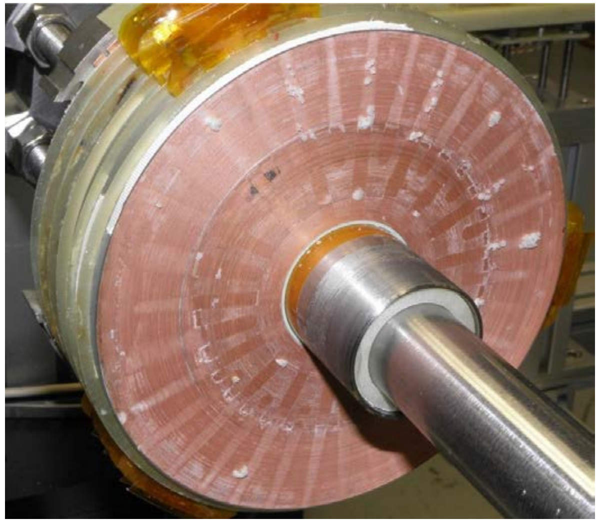


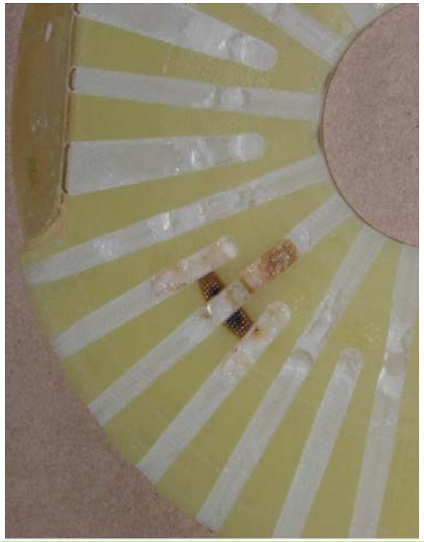
The damage

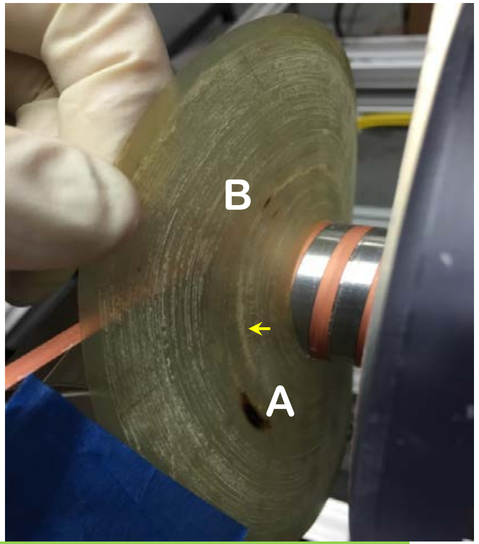
Three final spontaneous quenches induced at fast ramp rates during an attempted fatigue test caused degradation, after more than 100 safe triggered quenches at up to 27 T

- Unwinding showed 3 burned zones on G10 spacers
- Degradations were localized in the bottom double pancake with known low I_c.

- 1st quench at 229 A, 2.2 A/s, ramp started under 100 A.
- 2nd quench at 220 A, 2.2 A/s, ramp started at 200 A.
- 3rd quench at 200 A, 0.1 A/s.







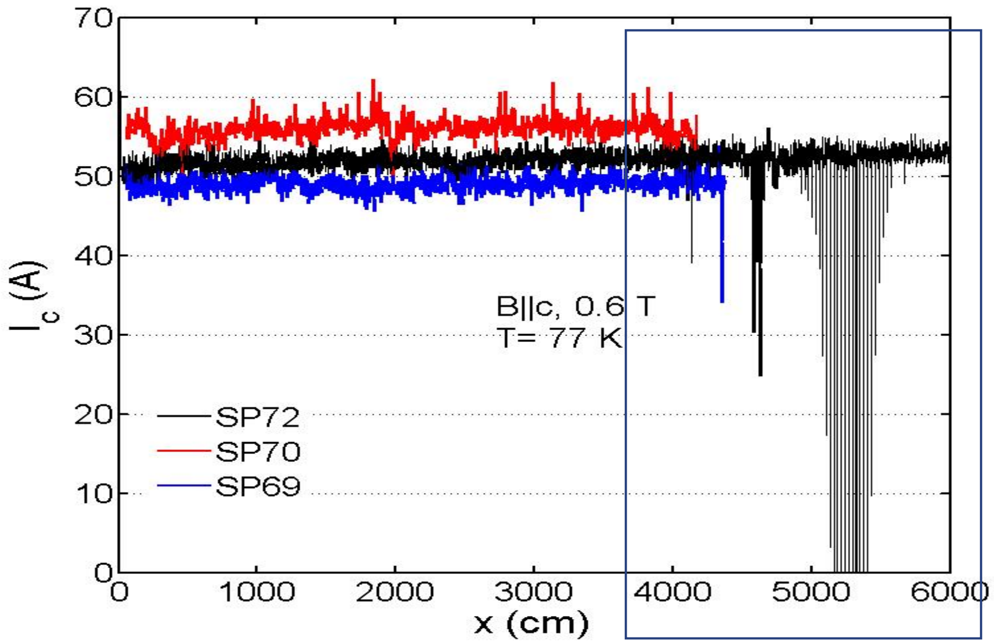
Normal ramp rate of all previous tests was ~0.5A/s

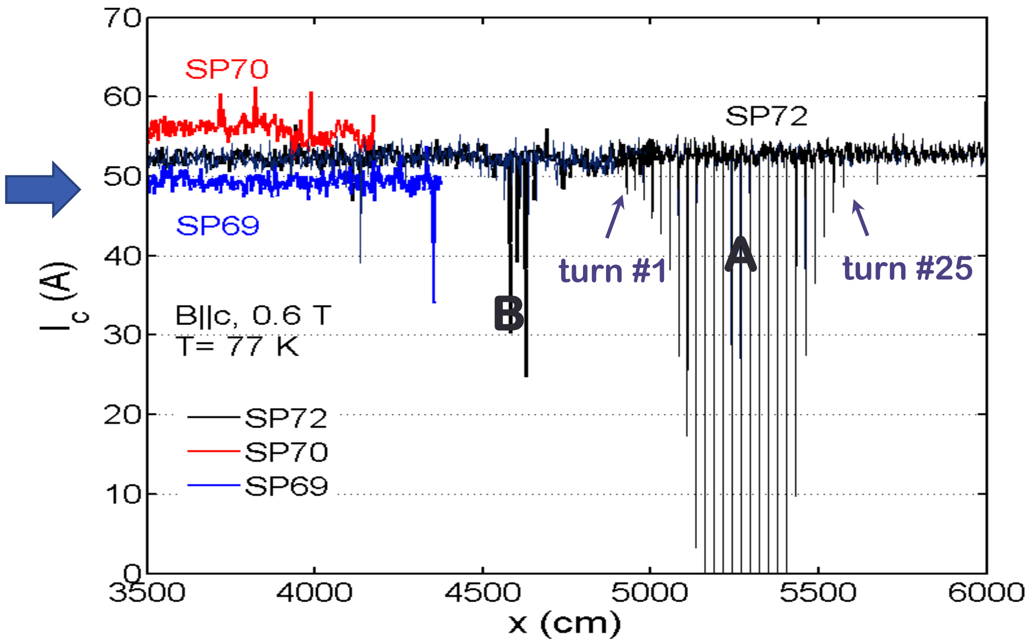
Highly localized burn damage zones seen after pancake disassembly – end pancake was then unwound and run through continuous *Ic* device YateStar.

Weijers *et al.* 32 T project team

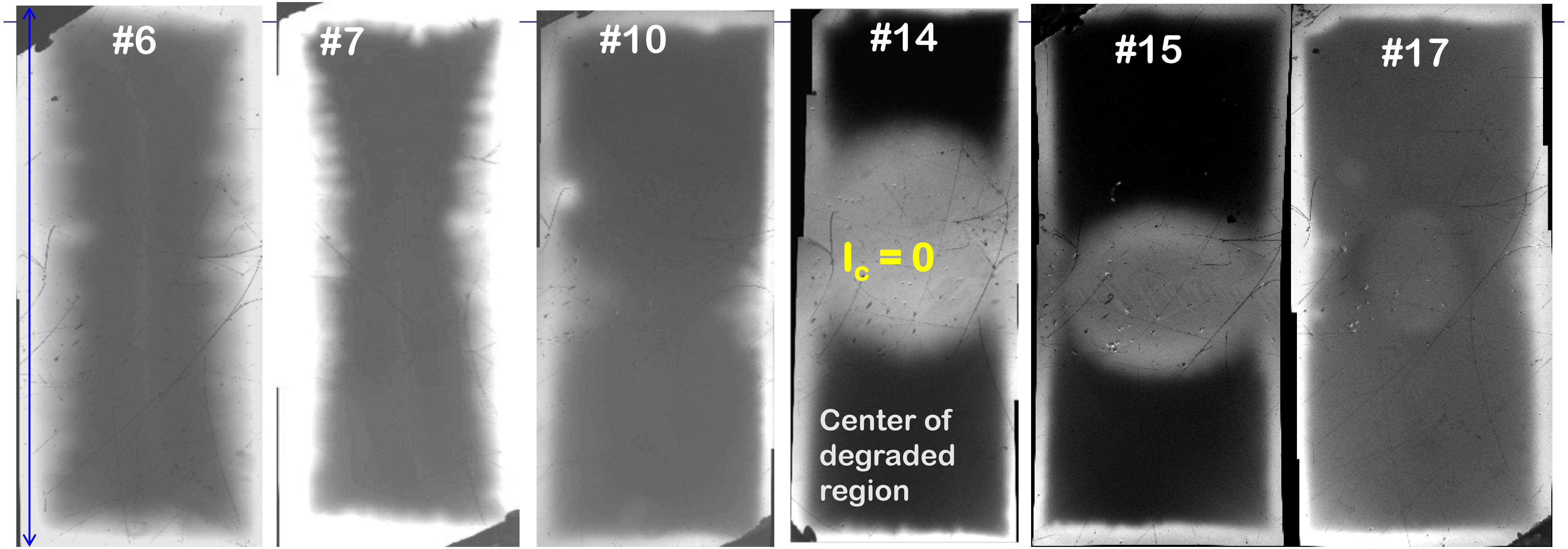
YateStar traces (made at 77 K in 0.6 T) show highly localized damage in burn regions only – otherwise no damage

- 3 final quenches showed progressive degradation of coil I_c (200A @14T background). Degradations were localized in the bottom double pancake.
- The 3 degraded zones (A, B and C) are of very different size and have quite different numbers of affected layers. A is by far the worst.





Period of Ic drops is the turn circumference



- Quench center is determined by the size of the damaged zone.
- For layers away from the center, damages are on the edges.

The striking result from Polyanskii's MO images is that the damaged zone is almost circular with 4 mm dia.

The peak temperature during quench was at least 779°C – progressive range of properties found in vicinity

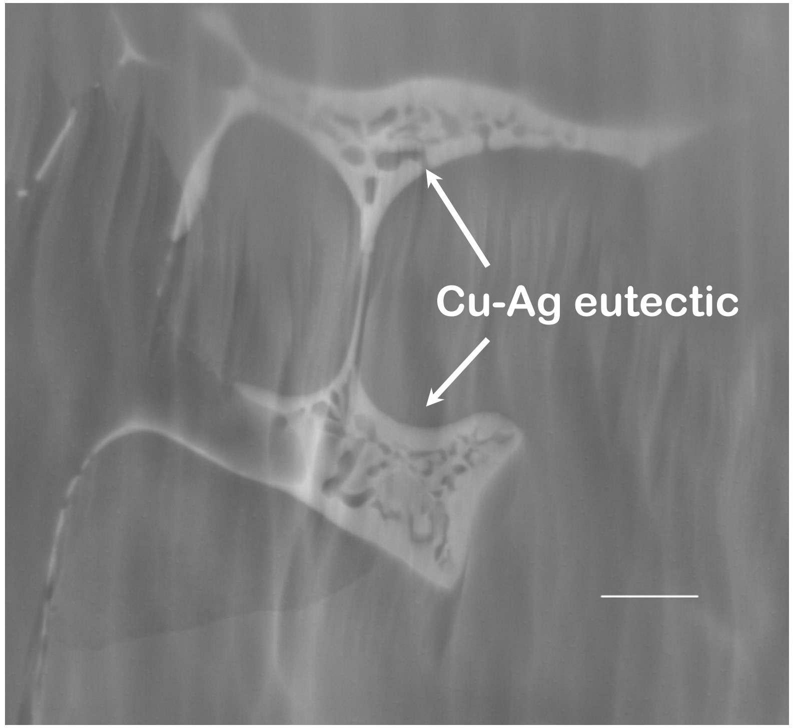
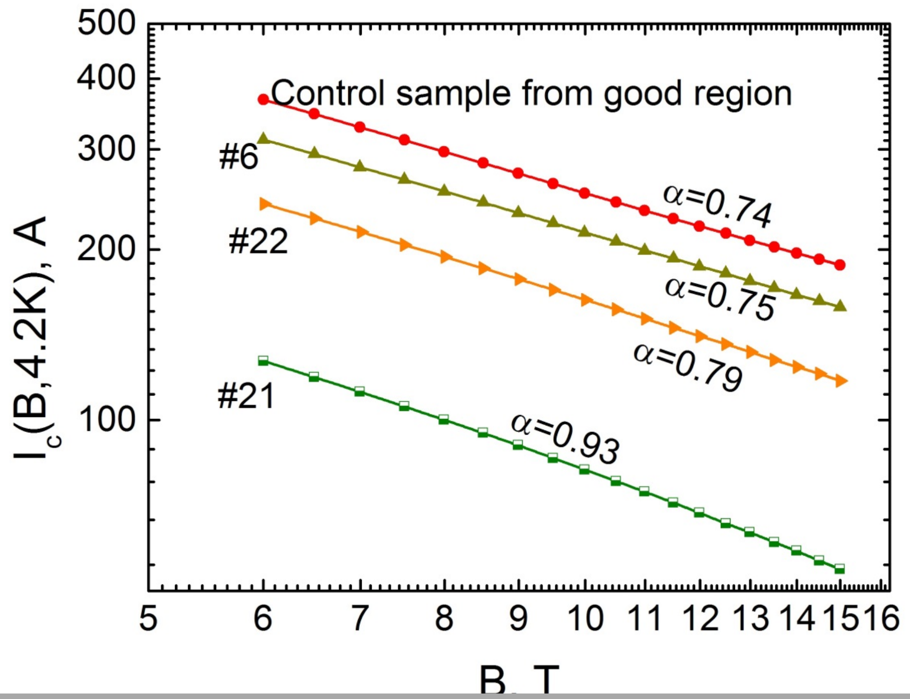


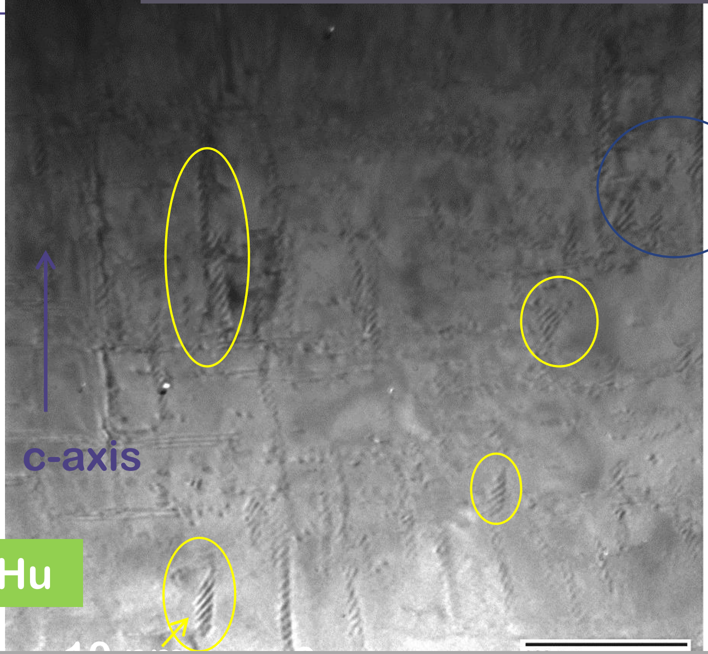
Image by Xinbo Hu

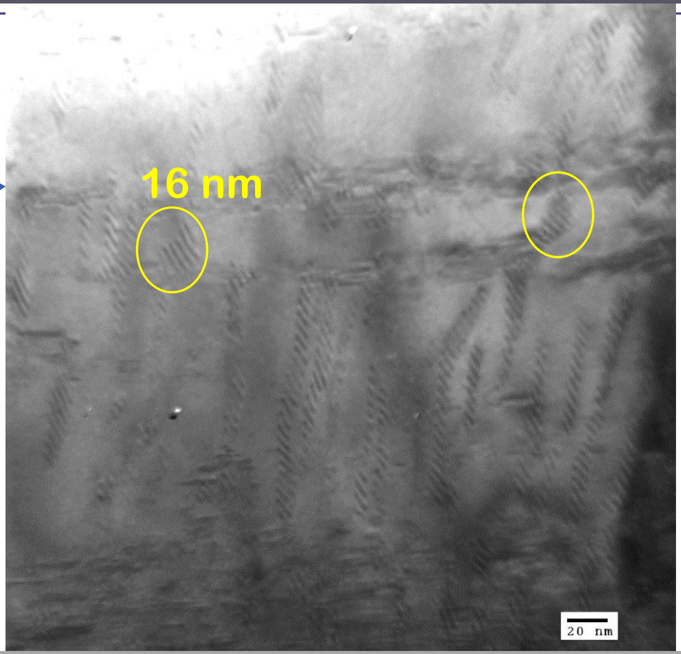


Marked change in α ($Jc \propto B^{-\alpha}$) value from good tape adjacent to damage zones, suggesting loss of oxygen by local heating (data by Abraimov)

Cause or consequence? Thicker BZO nanorods were found ~4 mm away from the hot spot edge of quench A – we believe this correlates to much lower Jc

Hu, X., Rossi, L., Stangl, A., Sinclair, J. W., Kametani, F., Abraimov, D., Polyanskii, A., Coulter, J. Y., Jaroszynski, J., & Larbalestier, D. C. (2017). An Experimental and Analytical Study of Periodic and Aperiodic Fluctuations in the Critical Current of Long Coated Conductors. *IEEE Transactions on Applied Superconductivity*, 27(4), 1-5.



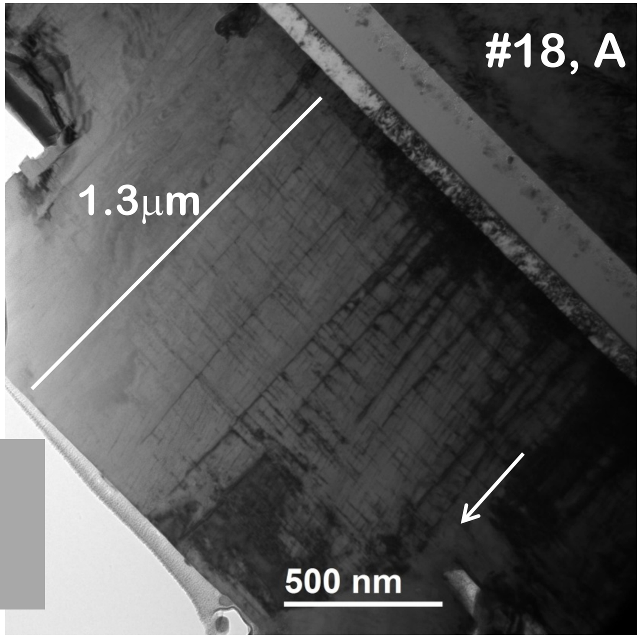


Images by Xinbo Hu

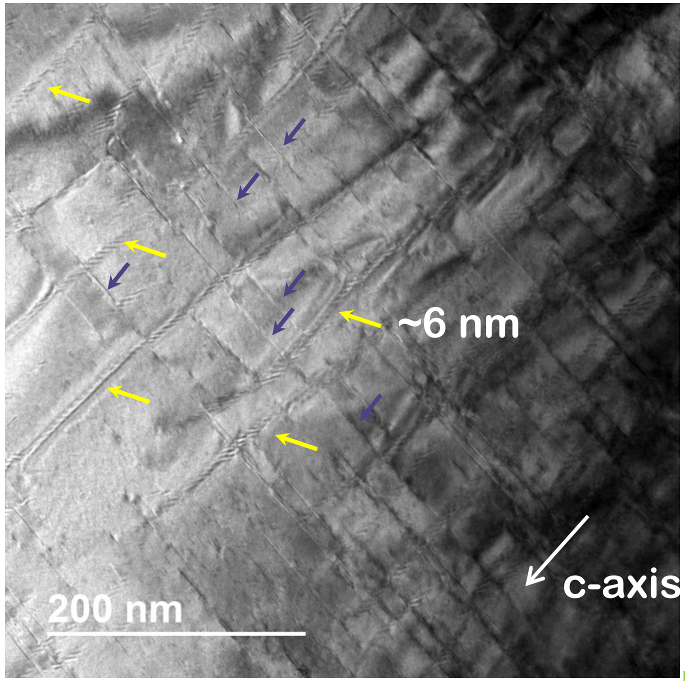
This is consistent with a local REBCO growth burp that does not produce the right nanostructure, losing about half of Jc at the ~25 T of the quenches. These locally lowered Jc regions may have caused the local overheating that only showed itself in the fast ramping condition where substantial heating of the end pancakes occurred.

- **BZO nanorods with diameter >10 nm appear more frequently in low Ic region.**

BZO nanorods ~6 nm in diameter are relatively uniform in regions far from the quench center of SP72



This is the expected nanostructure



Images by Xinbo Hu

- REBCO layer is expanded in thickness. Planar defects are observed in the *ab*-direction.
- In all the regions that we have checked, the diameter of the BZO nanorods is closely clustered in the range 5.5-7.5 nm, mostly around 6 nm.

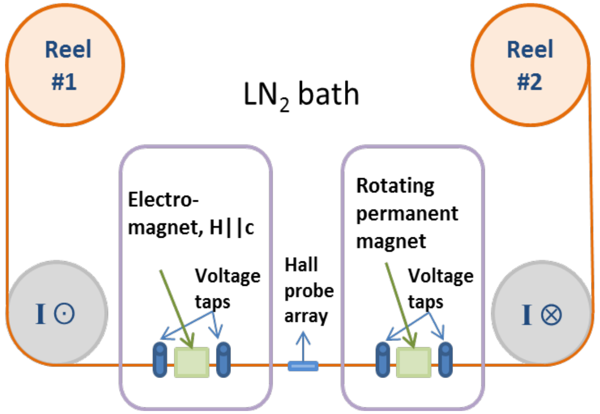
32 T prototype summary

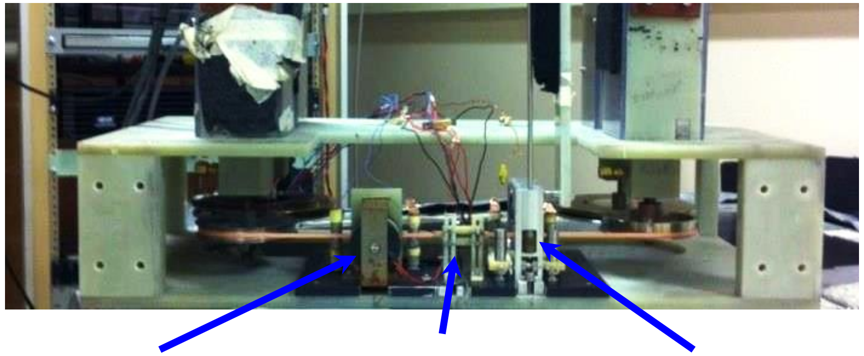
- The three final quenches occurred in an end pancake with low Ic and high radial field
- They were separated in space, and the energies released were different.
- The burned zones are very localized (few mm in diameter). The peak temperature during quench was at least 779°C (when Ag and Cu melted).
- Larger size BZO nanorods were observed close to the quench center A, which may indicate growth anomalies that cause locally reduced Ic and initiate the quenches.
  - Strain around optimized BZO nanorods generates O vacancies that supply about 50% of Jc in the 4 K, 10-20 T range

How predictable, repeatable and uniform are conductors?

- Along the length – our unique tool YateStar allows measurement of lengths up to 500 m at two orthogonal fields at 77 K, 0.6 T
  - This enables the uniformity of the nanostructure formation in the conductor to be verified since pinning by RE_2O_3 and $BaZrO_3$ (BZO) is highly visible
  - What is not visible is the large contribution to Jc at 4 K from O vacancies and other point defects induced by the large strain difference between BZO and REBCO
- Run-to-run variations were strong too (Ashleigh Francis *et al.* under review SuST 2019)
  - The variations in Jc(4K) were large while small at 77 K SF – the source of the variation appears to be differences in BZO and RE2O3 density, size and morphology

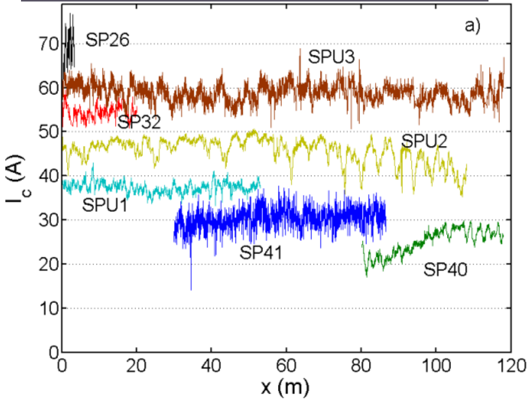
YateStar– unique instrument in ASC for length-wise transport and magnetization measurement with great spatial sensitivity (2 cm in transport in 0.6 T, 1 mm with Hall probes in remanent field)



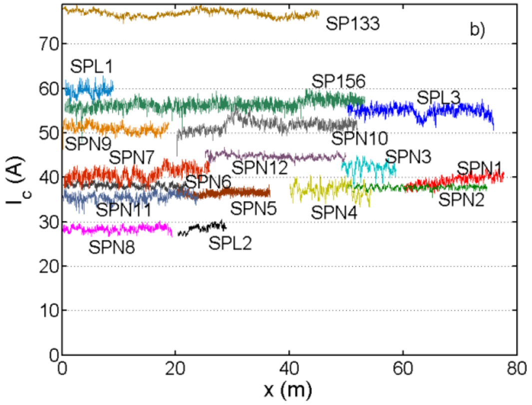


- Designed by Yates Coulter (NHMFL-LANL) and further developed at ASC by improvements to indexing, increase in length capability and measuring speed and addition of Hall probe array.
- Transport measurement: I_c (x, θ, B) [resolution ~2 cm]
  - ✓ Two channels for I_c(x) [normally perpendicular and parallel field]
  - ✓ Any interesting point for I_c(θ)
- Magnetization measurement: higher resolution [~ 1mm] and speed

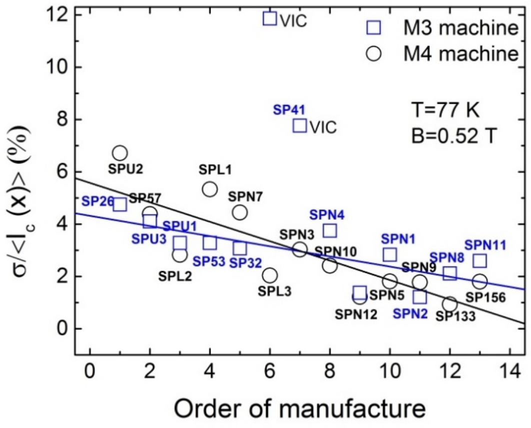
Received: 2010-2012



Received: 2013-2014



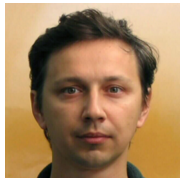
- We can quantitatively describe the I_c variation by standard deviation/mean value but we do not understand the reasons for variation yet.
- M3 and M4 are the two MOCVD reactors used by SuperPower.
- Different manufacturers have rather different standard deviation/mean values.

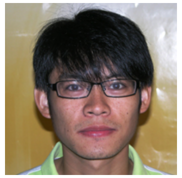


Xinbo Hu

IEEE CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), February 2020.
Plenary presentation PT-2 given at ACASC/Asian-ICMC/CSSJ Joint Conference, 6-9 January 2020, Okinawa, Japan.

Wide-ranging studies of Coated Conductors for Magnet Applications①





Ashleigh Francis, Dima Abraimov, Xinbo (Paul) Hu, Youri Viouchkov, Jan Jaroszynski, Anatoly Polyanskii, Fumitake Kametani* and David Larbalestier*,
Applied Superconductivity Center, National High Magnetic Field Laboratory
Florida State University, Tallahassee FL 32312
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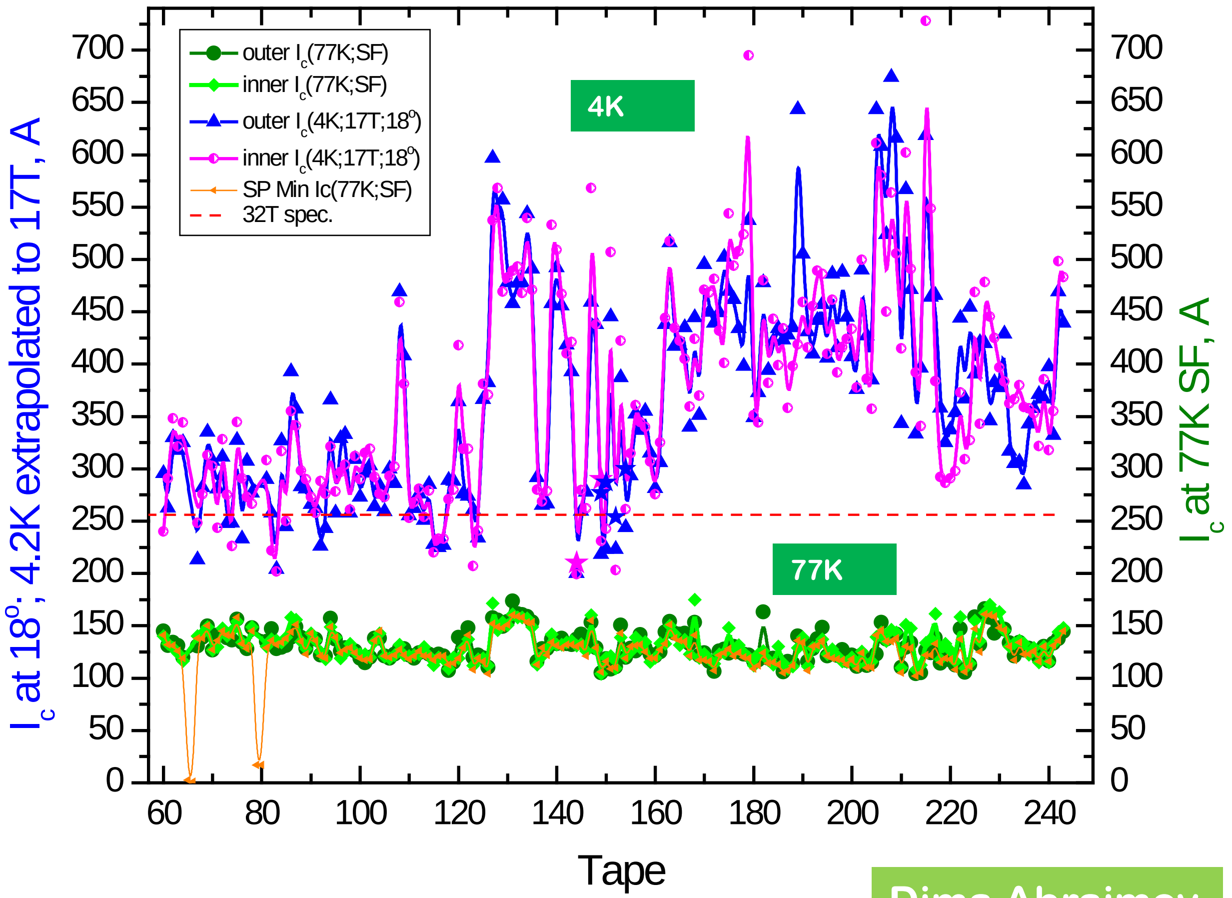
Tallahassee FL 32312

EUCAS Glasgow, Scotland, September 2-5, 2019

① Variable Temperature Transport Critical Current Measurements on REBCO Coated Conductors, by A. Francis, D. Abraimov, Y, Viouchkov, F. Kametani and DCL under review for SuST special edition

32 T Deliveries measured at 77 K sf and 4.2 K 18° off axis

- Minimum Ic specification was very well met by SuperPower
- Much bigger fluctuations in Ic(4K) than in Ic (77K)
- Multiple complications:
  - Deliveries over a 4 year period
  - Two different reactors used (M3 and M4)
  - M4 tends to make thicker REBCO than M3
- We realized that the pinning landscape at 4 K was very different than that at 77 K



Dima Abraimov

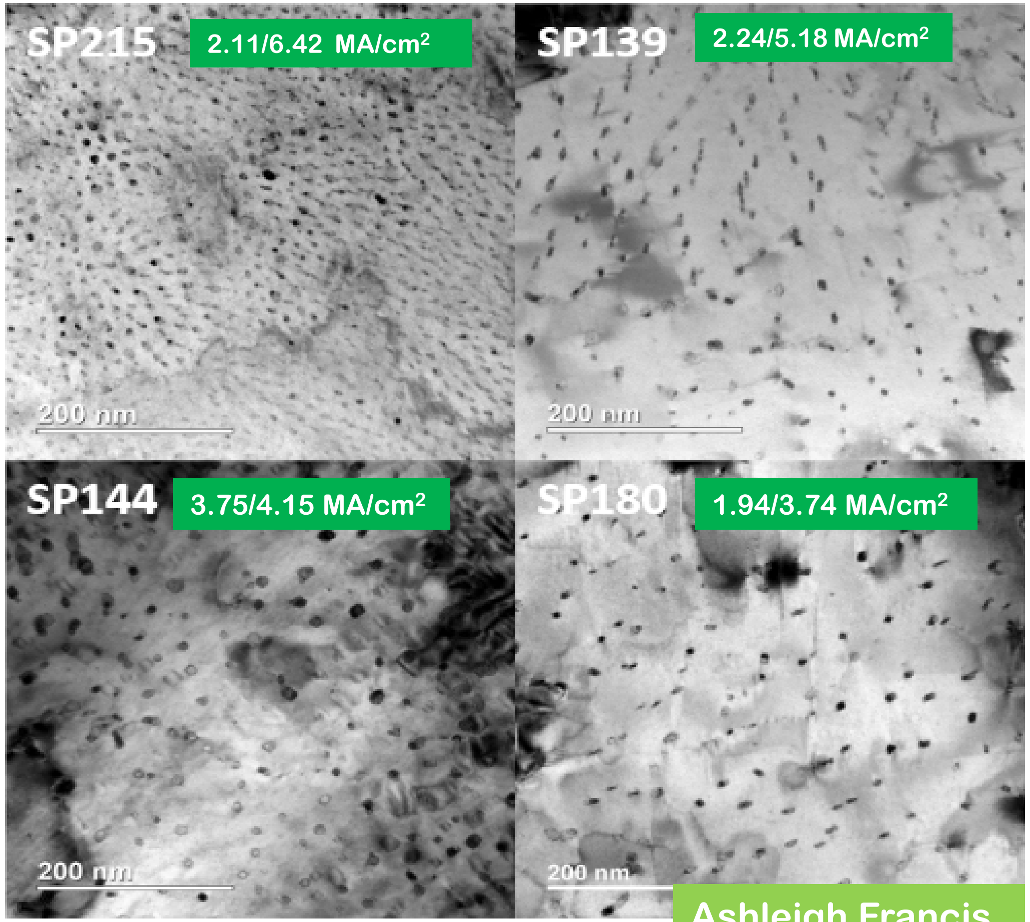
Jc variations correlate well to BZO nanostructure variations

Conductor Properties						
Conductor Designation	ReBCO thickness (µm)	T_c (K)	I_c(77 K, SF) (Amps) (B⊥tape)	I_c(4.2 K, 14 T) (Amps) (B⊥tape)	J_c(77 K, SF) (MA/cm^2) (B⊥tape)	J_c(4.2 K, 14 T) (MA/cm^2) (B⊥tape)
SP180	1.51		118	226	1.94	3.74
SP144	0.88	92.2	132	146	3.75	4.15
SP139	1.53	91.6	137	317	2.24	5.18
SP215	1.57	91.7	132	402	2.11	6.42

Table 1: Summary of Chosen Conductor Properties

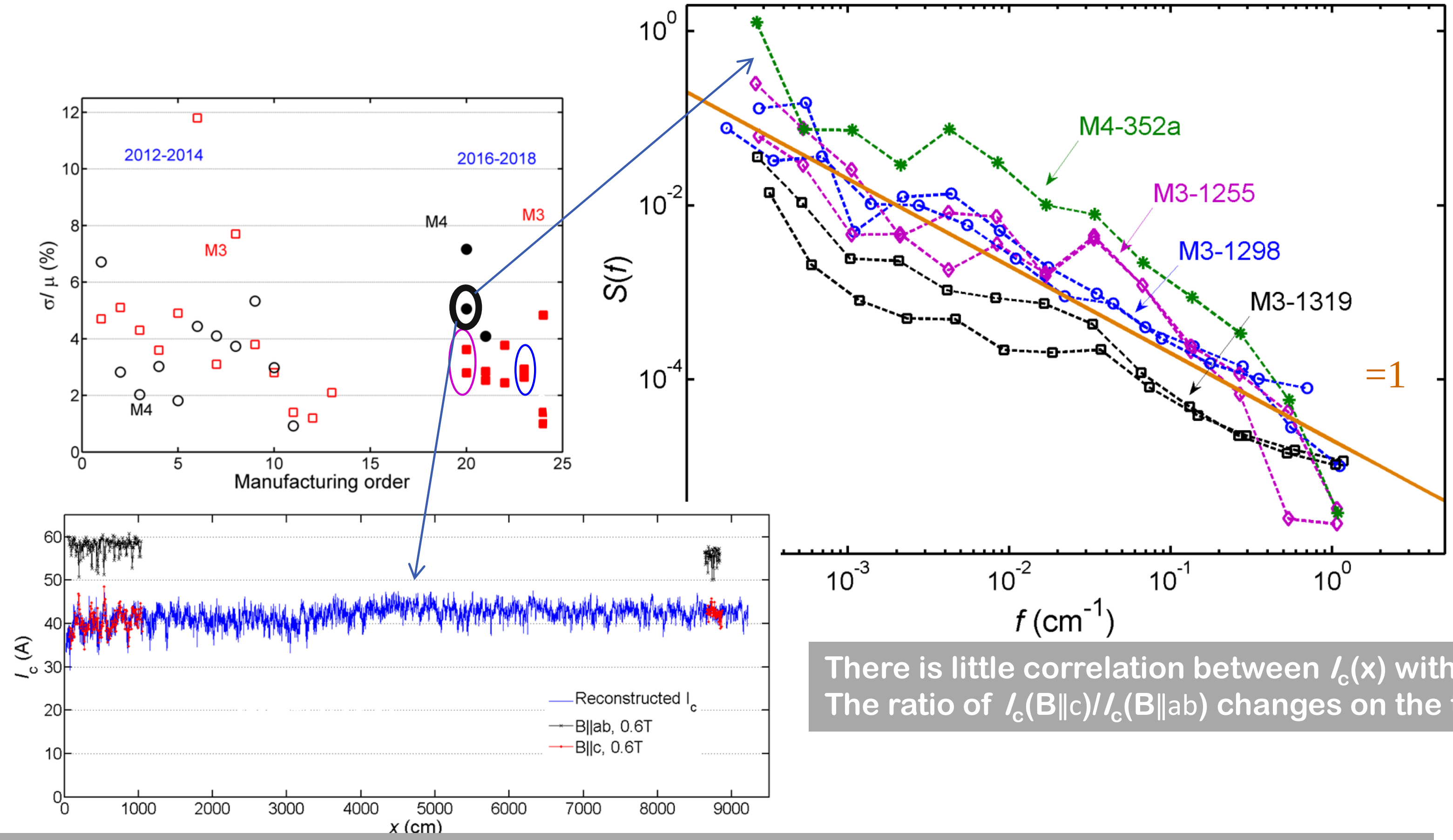
Material Properties							
Tape number	alpha (8 – 15 T)	B_{mat} (T)	$T_{0,max}$ (K)	BZO diameter (nm)	BZO spacing (nm)	BZO density (pin/nm^2)	Volume fraction of BZO (%)
SP180	0.84	4.6	27.8	5-6	28-32	4.87E-04	1.2
SP144	0.75	2.8	30.5	8-12	35-40	5.92E-04	4.6
SP139	0.67	5.4	28.8	6-10	20-25	6.82E-04	3.4
SP215	0.77	7.2	25.4	5-6	11-13	2.92E-03	6.9

- Ic SF values are very close – SuperPower hits their mark especially for SP 144, 130 and 215. But note that thickness varies from 0.88 to 1.57 um. The thinnest has much higher Jc at 77 K but is not special at 14 T 4K.
- Highest Jc(4K) is for finest and densest BZO pins
- Highest Jc(77K) is for BZO pins that are twice the diameter



Ashleigh Francis

Growth abnormalities during manufacture tend to show $\beta > 1$, probably due to vortex pinning variations induced by imperfect BZO nanorod growth



There is little correlation between $I_c(x)$ with B∥c and B∥ab. The ratio of I_c(B∥c)/I_c(B∥ab) changes on the two ends.

Paul Hu

A huge value of YateStar is that in-field measurements in 2 orientations makes vortex pinning changes become very clear. They show up the growth anomalies discussed above.

Strand Summary

- We cannot assume that the purchase of conductor to one single 77 K, self-field specification means that the 4 K, high-field properties will fall within the (small) 77 K specification variability
  - The vortex pinning at 4 K has a huge contribution from point defects that exert no role at 77 K
  - The point defect density is very sensitive to fluctuations of BZO and RE_2O_3 density and size
- Variations of Ic(77 K, 0.6 T B|| and ⊥) are very evident and show up local growth variabilities
  - Indeed we see that absolute values and the ratio of Ic(77 K, 0.6 T B|| and ⊥) vary significantly run to run
  - We are much less clear what these variations mean for the 4 K properties and for their potential in initiating damage like that seen in the 32 T prototype magnet damaged during (very) fast cycling

How about current sharing as an important way to mitigate risk for REBCO magnets?

A CORC® cable insert solenoid: the first high-temperature superconducting cable insert magnet tested at currents exceeding 4 kA in 14 T background magnetic field

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U.P. Trociewitz, D. Abraimov, A. Francis, J. Gillman, D.S. Davis, Y. Kim, V. Griffin, G. Miller, H.W. Weijers, L.D. Cooley, and D.C. Larbalestier

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Lawrence Berkeley National Laboratory, Berkeley, California 94720, U.S.A.

Submitted to SuST January 2020 after test in December 2019 – joint ACT-NHMFL SBIR Award from DOE-OHEP

The virtues of current sharing; CORC cable magnet

CORC® cable layout

- 3.2 mm solid copper former
- 28 REBCO tapes of 3 mm width containing 30 μm substrates
- 4.56 mm CORC® cable outer diameter
- 19 meters of CORC® cable length
- 800 meters of tape length

CORC® magnet layout

- 50 mm inner radius, 71.5 mm outer radius, 60 mm height
- 4 layers, 45 turns
- Wet-wound with Stycast 2850
- Stainless steel overbanding between layers

Advanced Conductor Technologies
www.advancedconductor.com

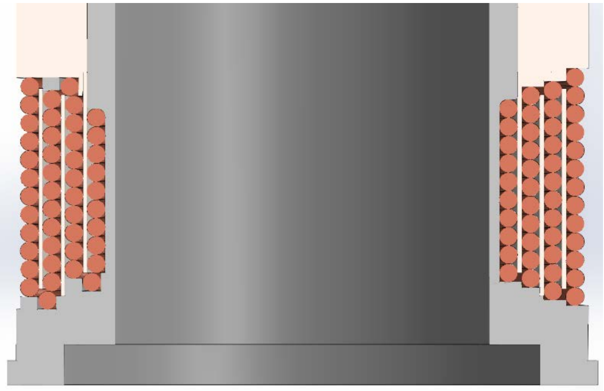
CORC® insert magnet test in 14 T background field

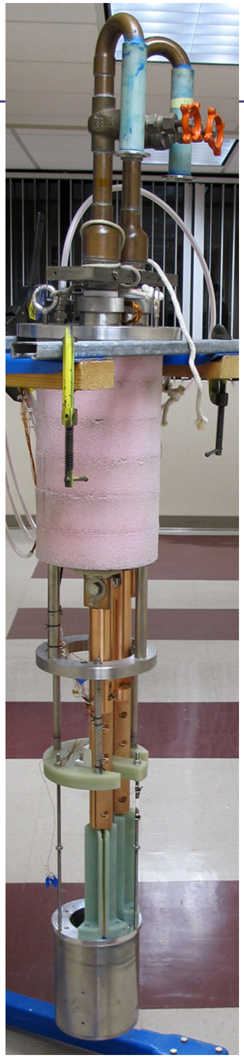
"First multi-kA HTS insert magnet tested in a background magnetic field"

Danko van der Laan & Jeremy Weiss
Advanced Conductor Technologies, Boulder, Colorado, USA

Ulf Trociewitz, Dima Abraimov, Daniel Davis, George Miller, Van Griffin, Youngjae Kim, James Gillman, Ashleigh Francis, Huub Weijers, Lance Cooley & David Larbalestier
National High Magnetic Field Laboratory, Tallahassee, Florida, USA

Xiaorong Wang
Lawrence Berkeley National Laboratory, Berkeley, California, USA

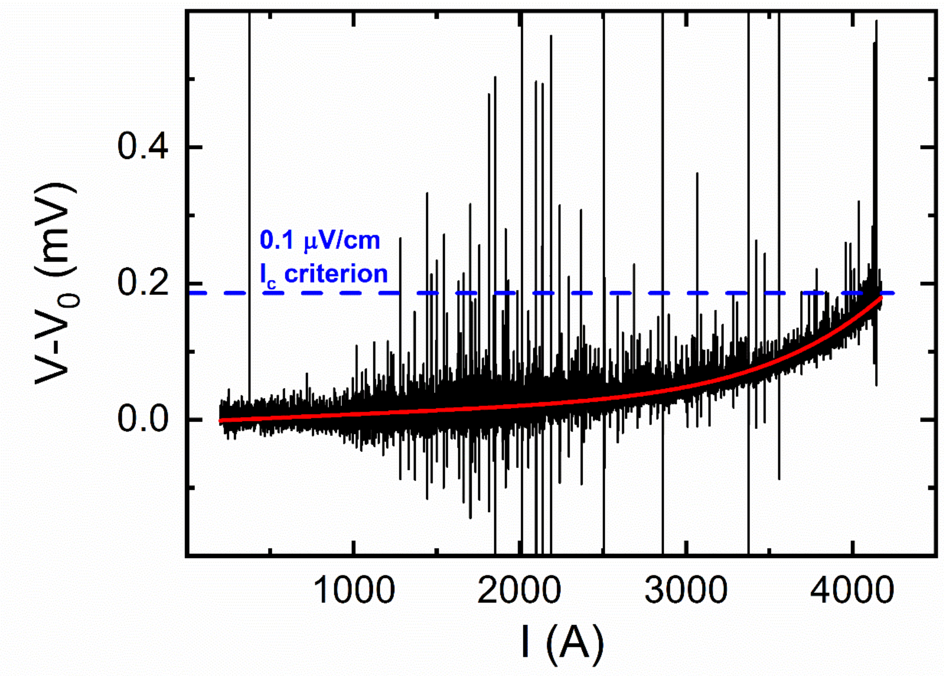




CORC® Magnet Test: 14 T Background Field

Results in 14 T background field

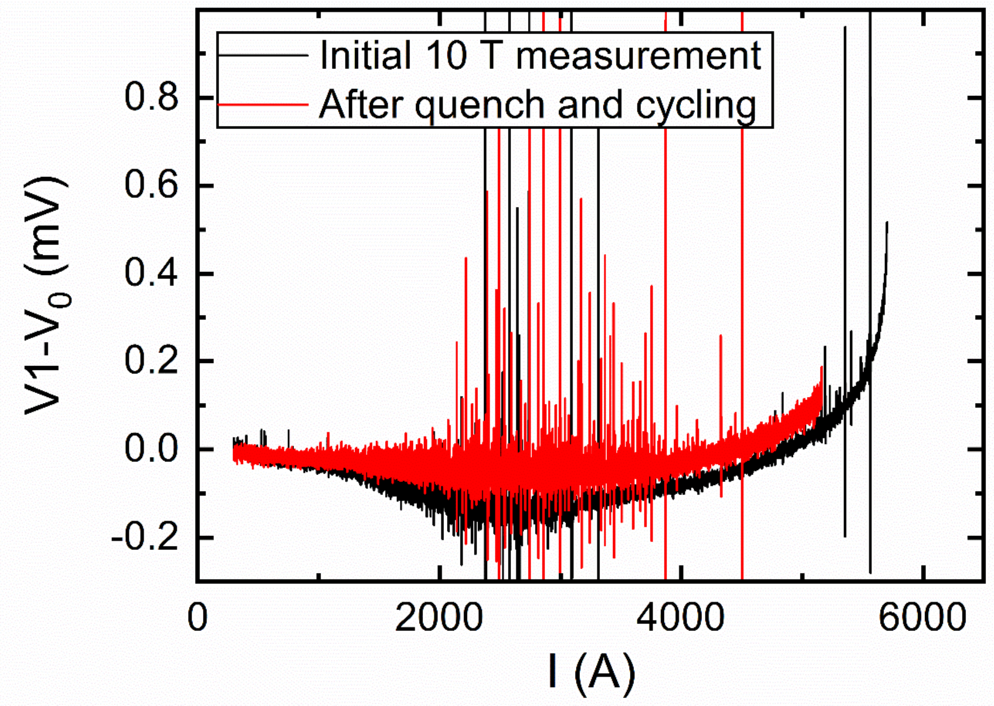
- Maximum current was limited to 4,200 A to avoid triggering outsert quench – CORC magnet was clearly in STABLE current sharing
- I_c = 4,404 @ 0.1 μV/cm
- Contact resistance 11.1 nΩ
- 15.86 T central field
- 16.77 T on conductor
- Peak Hoop stress 275 MPa



CORC® Magnet Test: Final Test at 10 T

Performance after measurement campaign

- Black curve: first measurement at 10 T followed by quench protection trigger
- Red curve: final measurement at 10 T after 10, 12 and 14 T tests, and 10 stress cycles at 10 T to 5 kA (220 MPa Hoop stress)
- First 10 T test: I_c = 5,410 @ 0.1 μV/cm
- Final 10 T test: I_c = 5,315 @ 0.1 μV/cm (16th run)



No degradation in CORC® performance after full measurement campaign

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NATIONAL HIGH MAGNETIC FIELD LABORATORY

Summary of CORC Coil Test

Successful test of CORC® cable insert solenoid at 14 T background fields

- CORC® insert coil containing 19 meters of 28-tape CORC® cable
- CORC® insert was wet-wound within one day
- CORC® insert I_c (1 μV/cm) of 6,485 A at 10 T background field suggest 86 % of total tape I_c
- CORC® insert I_c (0.1 μV/cm) of 4,404 A at 14 T background field
- Central field at I_c of 15.86 T, peak field on conductor of 16.77 T
- No performance degradation after 16 high-current runs at high background field
- CORC® insert operation very stable, allowed slow current ramp down without insert quench or heating after reaching I_c

Results show:

- **First multi-kA HTS insert magnet test in a background magnetic field**
- **Multi-tape conductors, such as fully isotropic CORC® cables, offer a clear benefit over single-tape conductors for high-field magnets, because they allow current sharing between tapes, making them much less susceptible to local defects**

Advanced Conductor Technologies
www.advancedconductor.com

NATIONAL HIGH MAGNETIC FIELD LABORATORY

Summary Thoughts on REBCO CC in UHF Magnets

- Our High Field Magnets (can) put the conductor into danger
- The Coated Conductor is not really the cartoon that we find in brochures
- There are stress concentrations at slit edges that may be highly variable
  - Along length, run-to-run depending on maintenance of the slitting tool
  - Manufacturer to manufacturer
- There are both weak and strong bonding planes in a Coated Conductor
  - Strong at Ag-REBCO interface but weak at the REBCO-Buffer interface
  - Screening current stresses may cause significant variability in response and local response may be statistical (Weibull approach needed?)
- We need good magnet test beds and good post mortems with distributed reports of the findings

Final thoughts

- No magnet is ever better than its conductor, so….
- What really is your coated conductor?

Build in current sharing!